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LCA STUDY OF THE UBC DISTRICT ENERGY CENTRE – HOT WATER PLANT

STAGE 1: STRUCTURAL ELEMENTS

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Table of Contents

List of Tables

List of Figures

1.0 Introduction

1.1 Overview

In this work, a screening level "cradle-to-gate" life cycle assessment (LCA) of two proposed University of British Columbia (UBC) District Energy Centre (DEC) structural systems options was performed. The two options are [1] a structural steel system, and [2] a "Hybrid" system in which a significant share of the steel structure is substituted with glulam and cross laminated timber (CLT). The LCA results have been incorporated with Hanscomb Ltd.'s cost estimate information in order to provide UBC Project Services and the DEC design team an integrated economic-environmental analysis. In addition, externality cost estimates associated with the predicted emissions are provided in order to gauge their significance relative to the direct costs.

When only those elements that differ between design cases are compared, the Hybrid design shows a reduction in global warming emissions of 26%, reductions of between 18% and 64% for other environmental impacts analyzed, and an increase in direct cost of 31%.

1.2 Purpose of the Assessment

The purpose of this work is to use the integrated economic-environmental results in the DEC design decision-making process.

2.0 General Assessment Information

2.1 Functional Equivalent

The new European building LCA standard EN 15978[1] defines a functional equivalent as "the quantified functional requirements and/or technical requirements for a building or an assembled system (part of works) for use as a basis for comparison". The functional equivalent of Stage 1 of the UBC DEC LCA work includes the following characteristics:

- Building type: an institutional district energy centre.
- Technical and functional requirements: the structure meets the requirements of the 2012 British Columbia Building Code.

Since this work is a cradle-to-gate analysis of structural system options, other characteristics such as building pattern of use and required service life need not be specifically defined but are assumed equivalent across the cases considered.

[1] EN 15978:2011 *Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method*

2.2 Objects of Assessment

Table 1 presents the building elements considered in analysis according to the Canadian Institute of Quantity Surveyors (CIQS) elemental format. In general, the objects of assessment include elements related directly to structure (i.e. A11, A21, A22, and A23), as well as other elements that include structural aspects (A32, B11). Some of the element items have been excluded from scope, most notably stairs. Additionally, the cost of concrete formwork has been included in analysis, but excluded from the environmental assessment.

Table 1: DEC Objects of Assessment Summary

<table>
<tr><th>Building Element</th><th>OPTION 1: Hybrid Design</th><th>OPTION 2: Steel Design</th></tr>
<tr><td>A11 Foundations</td><td colspan="2">Perimeter and interior walls supported by cast-in-place foundation wall and strip footings; perimeter and interior columns supported by piers and pad footings</td></tr>
<tr><td>A21 Lowest Floor Construction</td><td colspan="2">150mm and 100mm cast-in-place slab on grade on aggregate sub base</td></tr>
<tr><td rowspan="2">A22 Upper Floor Construction</td><td>Second Floor: 239mm CLT floor with 50mm concrete topping and 210mm Comfloor composite floor slab supported glulam beams and steel columns</td><td>Second Floor: 210mm Comfloor composite floor slab supported by steel beams and columns</td></tr>
<tr><td colspan="2">Mezzanine: Metal grate supported by steel beams and columns</td></tr>
<tr><td rowspan="3">A23 Roof Construction</td><td>External walls: 200mm cast-in-place concrete and 239mm CLT walls</td><td>External walls: Steel studs infill with exterior sheathing and interior GWB, and 200mm CMU walls</td></tr>
<tr><td>Lower roof: 239mm CLT and 210mm Comfloor composite deck supported by glulam and steel beams, and steel columns</td><td>Lower roof: 210mm Comfloor composite deck supported by steel beams and columns</td></tr>
<tr><td>Upper roof: 239mm CLT deck supported by glulam and steel beams and columns</td><td>Lower roof: 210mm Comfloor deck supported by steel beams and columns</td></tr>
<tr><td>A32 Walls Above Grade</td><td colspan="2">Aluminum framed glazed curtain wall, and aluminum composite panel and perforated metal panel projections c/w steel supports</td></tr>
<tr><td rowspan="2">B11 Partitions</td><td colspan="2">Non-structural: Gypsum board on both sides of metal studs c/w sounds attenuation batts, and metal framed glazed screens</td></tr>
<tr><td>Structural: 99mm and 239mm CLT, and 200mm cast-in-place concrete walls</td><td>Structural: 200mm CMU walls</td></tr>
</table>

Table 1 shows that differences between the two design options analyzed are found within the Upper Floor and Roof Construction, and Partitions elements (A22, A23, and B11), with the remaining elements the same across cases.

All material takeoffs used as LCA model inputs come from Hanscomb's cost estimate report (see Section 3.3), with the exception of elements A11 (Foundation), which were estimated by Coldsteam according to the structural drawings provided by Fast + EPP.

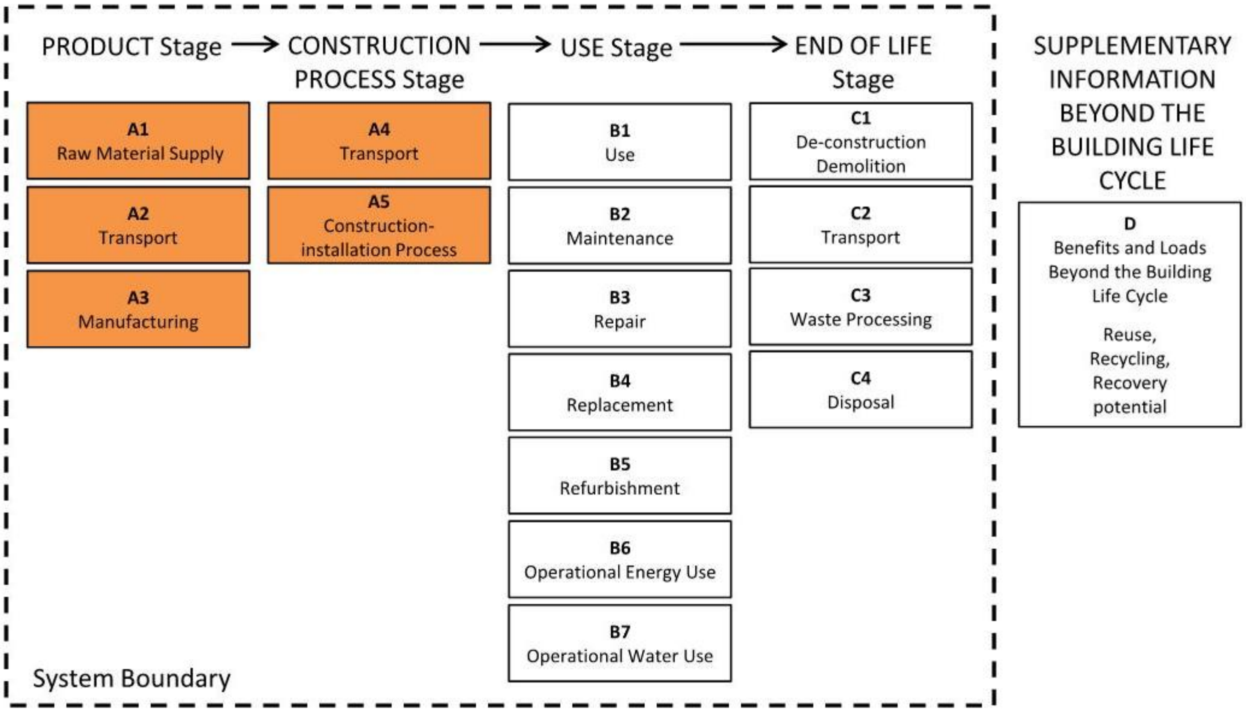
See Appendices B and C for a detailed summary of analysis scope, what is accounted for by each element item, and estimated material quantities.

2.3 Assessment System Boundary

Figure 1 illustrates how the processes forming a typical building life cycle are classified according to EN 15978. The life cycle of buildings includes of four stages, each comprised of "information modules" labelled A1 through C4. An additional module "D" accounts for benefits outside the system boundary of the object of assessment, and includes the benefits of, for example, recycling and reusing materials at end of life. The scope of this assessment includes the modules shown highlighted orange; the analysis is considered "cradle-to-gate" and therefore includes life cycle effects of the building up to the end of its initial construction.

Only building material use derived environmental effects, or "embodied effects", are considered. It should be noted that operating energy can be responsible for a significant share of environmental flows. For this phase of the DEC LCA work, it was deemed acceptable not to quantify these effects since [1] it is assumed that each design has comparable thermal properties and hence energy use, [2] the objective of this study is to analyze material use impacts of structural system options.

Figure 1: Building LCA System Boundary According to EN 15978 (analysis scope shown orange)



3.2 Scenarios for Defining the Building Life Cycle

Assumptions are required to complete the building scenarios due to [1] not all information being practically available to the assessor and [2] buildings have long and uncertain services lives. For the cradle-to-gate analysis presented herein, the following scenarios have been assumed:

- Material transportation distances and modes from plant gate to construction site are estimated values taken from the *Athena Transportation Database* (Vancouver location).
- On-site construction waste due to cut-offs, or unused, lost, or damaged materials are accounted for by multiplying the material quantities by waste factors. Waste factor estimates are taken from the *Athena Construction Waste Factor Database*.

3.0 Data Sources

3.1 Life Cycle Inventory (LCI) Data

LCI data, i.e. the material and energy inputs, and air, water, land outputs from the processes, were sourced from the Athena LCI Database. The database reflects industry average construction product and service conditions, and is currently the most comprehensive North American LCI dataset on construction products. It contains process LCI information that covers a building's life cycle stages from the "cradle" (natural resource extraction) through to its "grave" (end-of-life). Details of Athena LCI Database can be found on the Athena Sustainable Materials Institute webpage[2].

The Athena LCI Database currently contains profiles for:

- Structural products (e.g. 30MPa concrete, small dimension lumber, wide flange steel)
- Envelope products (e.g. cladding, insulation, roofing materials)
- Operating energy (e.g. natural gas, diesel, electricity)

Of particular importance to this project is that the database currently lacks CLT LCI data. For the purpose of this report, the environmental profile for glulam was used as a surrogate to estimate the effects of CLT. This was deemed acceptable since both glulam and CLT are made from sawn lumber members that are bonded by a resin; life cycle extraction and manufacturing processes to produce the products are therefore assumed similar.

3.2 Life Cycle Impact Assessment (LCIA) Methodology

For this study, Coldstream Consulting has relied on ISO 21931-1[3] to identify the various impact categories to be included and the US EPA's *Tool for the Reduction and Assessment of Chemical and other environmental Impacts* (TRACI 2, version 4) as the LCIA methodology. ISO 21931-1 provides an internationally accepted scope of impact

[2] http://www.athenasmi.org/our-software-data/lca-databases/

[3] ISO 21931-1:2010 *Sustainability in Construction - Framework for methods of assessment of the environmental performance of construction works. Part 1: Buildings*

assessment categories that should be supported for building sustainability metric analysis, while the TRACI LCIA method provides a North American context for the actual measures to be supported. The impact indicators advocated by ISO 21931-1 that will be the basis of this report include:

1. Fossil fuel use[4] – MJ
2. Global warming potential – kg CO_2 equivalents
3. Acidification potential – moles H^+ equivalents
4. Eutrophication potential – kg N equivalents
5. Ozone depletion potential – kg CFC-11 equivalents
6. Smog potential – kg O_3 equivalents

This report also presents the following additional environmental impact indicator:

7. Human health (HH) criteria pollutants – kg PM_{10} equivalents

Descriptions of the seven impact indicators considered are provided in Appendix A.

3.3 Construction Costs

The direct costs of construction presented in this work are taken from Hanscomb's design development phase cost estimate report, dated February 25 (pdf file name: Hanscomb Estimate February 25). The sections of the report that are relevant to this analysis are presented in Appendices B and C.

Externality cost estimates have additionally been analyzed in this work to assess their order of magnitude and evaluate their significance relative to direct cost. This analysis enables an interpretation of societal costs that are unrealized due to a lack of legislation or other market mechanism.

Unit externality cost estimates for the six emissions environmental indicators (fossil fuel use is not considered) come from a report titled *Internalizing Environmental Pollution Costs within a Life Cycle Costing Decision-Making Process* (2011), by Jamie Meil, Managing Director of the Athena Sustainable Materials Institute. The report employs a systematic approach using environmental marginal damage valuations to establish economic indicators for environmental performance.

For example, the Athena report estimates a cost of 30$/tonne CO_2 eq. of global warming potential (GWP) emissions, based on the "middle marginal damage" value established by an extensive 2009 National Research Council (NRC) review of known literature.

[4] Named "use of non-renewable primary energy" in ISO 21931-1

4.0 Results

This section presents integrated economic and environmental results for the two design cases considered. Tables 2 and 3 show numerical results for the Hybrid and Steel designs, respectively, for each building element item considered in LCA analysis. As previously noted, not all items were assessed for all elements and therefore some of the results represent a subset of those presented in the Hanscomb cost estimate report. The total costs of elements considered in analysis are $3,198,500 and $2,812,800 for the Hybrid and Steel designs, respectively. These costs account for 60% and 57% of the the net building cost, excluding Site and Ancillary Work (elements D1, D2), and General Requirements & Fees and Allowances (elements Z1, Z2). Similarly, the total cost of the Hybrid design wood components (i.e. CLT and glulam) is $886,500, accounting for 17% of the net building cost.

Figures 2 and 3 that follow show the resulting contributions each element makes to the total indicator results. For both design cases, the contributions are generally similar to that of the direct costs.

Figures 4 and 5 show integrated results for each case, normalized to the Steel design, and serve to highlight their relative performance. When all elements are considered (Figure 4), the Hybrid design impacts are between 57% and 97% that of the Steel design; when only those elements that differ (A22, A23, B11) are considered (Figure 5), the Hybrid design impacts are between 36% and 82% that of the Steel design. It can therefore be concluded that the Hybrid design performs better environmentally, but has a higher total cost, despite savings in externality costs.

Figures 6 and 7 present global warming potential comparison results in more detail. The results show a difference of 84.7 tonnes CO_2 eq. between cases - to put that value in perspective, assuming the annual direct emissions of a passenger car are 5.5 tonnes CO_2 eq.[5], the reduction is equivalent to removing approximately 15½ cars from the road for one year.

Finally, Figures 8 and 9 illustrate how sensitive the Hybrid design results are to increased use of fly ash as a supplementary cementing material (SCM) in concrete. In this analysis, the fly ash content of cement is increased from 9% (i.e. the Athena LCI Database “average” value) to 35%, and costs are assumed to be the same. As shown in Figure 8, the Hybrid design could attain further reductions in impact relative to the Steel design, up to 2% to 9% across the seven indicators reported. Figure 9 highlights the elements that contribute to reductions in global warming potential, namely those elements that use concrete (A11, A21, A22, A23, B11). Up to 37.3 tonnes CO_2 eq. of additional savings in global warming emissions could be attained for the Hybrid design.

[5] Source: US EPA (http://www.epa.gov/cpd/pdf/brochure.pdf)

Table 2: Hybrid Design Economic-Environmental Results

Element	Direct Cost (CAD $)	Externality Cost (CAD $)	Total Cost ($)	Fossil Fuel Use (MJ)	Global Warming Potential (kg CO_2 eq)	Acidification Potential (moles H+ eq)	HH Criteria (kg PM10 eq)	Eutrophication Potential (kg N eq)	Ozone Depletion Potential (kg CFC-11 eq)	Smog Potential (kg O_3 eq)
All Elements	3,198,500	69,119	3,267,619	7,027,390	581,436	244,089	5,961	234.88826	2.07E-03	54,475
A11 Foundations	416,100	6,959	423,059	677,106	93,934	32,443	396.71307	28.592775	5.07E-04	12,207
A11.1 Foundations	416,100	6,959	423,059	677,106	93,934	32,443	397	29	5.07E-04	12,207
A21 Lowest Floor Construction	173,100	23,525	196,625	871,190	96,625	29,722	2,628	33.665572	4.22E-04	10,755
A21.1 150mm Concrete Slab on Grade	76,400	15,672	92,072	424,346	46,032	13,845	1,853	15	1.91E-04	5,054
A21.2 100mm Concrete Slab on Grade	21,700	4,956	26,656	111,895	11,278	3,317	605	4	4.29E-05	1,198
A21.3 Housekeeping Pads	75,000	2,896	77,896	334,949	39,316	12,560	170	14	1.88E-04	4,503
A22 Upper Floor Construction	229,900	2,247	232,147	642,525	43,705	11,692	83.033067	18.659226	2.10E-05	1,786
A22.1 CLT Floor	80,900	983	81,883	213,222	14,416	5,097	53	4	1.73E-05	1,145
A22.2 Composite Floor Slab	2,900	87	2,987	16,194	1,496	389	4	1	3.68E-06	100
A22.3 Glulam Beams	3,100	12	3,112	3,198	188	68	1	0	2.48E-09	12
A22.4 Structural Steel Columns	2,000	23	2,023	9,798	472	166	1	0	1.28E-09	12
A22.7 Structural Steel Beams	68,400	23	68,423	9,798	472	166	1	0	1.28E-09	12
A22.8 Structural Steel Columns	9,500	106	9,606	45,592	2,189	767	3	1	5.61E-09	55
A22.9 Metal Grate Floor System	63,100	1,013	64,113	344,723	24,472	5,040	21	12	5.26E-08	450
A23 Roof Construction	978,400	10,019	988,419	2,298,934	155,273	54,313	500.80422	60.067432	2.36E-04	12,160
A23.1 Concrete Walls - Exterior	193,600	2,853	196,453	321,260	39,324	13,761	157	15	1.98E-04	5,193
A23.2 CLT Walls - Exterior	133,900	1,199	135,099	310,132	18,170	6,619	63	5	2.33E-07	1,222
A23.3 CLT Roof Deck	239,800	2,346	242,146	606,569	35,536	12,946	123	10	4.56E-07	2,390
A23.4 Composite Roof Deck	26,800	834	27,634	151,172	14,199	3,736	39	5	3.68E-05	990
A23.5 Structural Steel Beams	10,700	109	10,809	47,825	2,271	785	3	2	5.88E-09	58
A23.6 Glulam Beams	74,100	293	74,393	75,665	4,433	1,614	15	1	5.69E-08	298
A23.7 CLT Beam	6,200	56	6,256	14,378	843	306	3	0	1.09E-08	57
A23.8 Structural Steel Columns	5,100	59	5,159	25,092	1,212	428	2	1	3.13E-09	30
A23.9 CLT Roof Deck	101,500	993	102,493	256,855	15,048	5,482	52	4	1.93E-07	1,012
A23.10 Structural Steel Beams	30,200	261	30,461	118,673	5,346	1,893	7	6	1.54E-08	182
A23.11 Glulam Beams	56,000	210	56,210	54,334	3,183	1,159	11	1	4.09E-08	214
A23.12 Structural Steel Columns	52,700	611	53,311	261,419	12,623	4,461	17	8	3.17E-08	314
A23.13 Glulam Columns	44,800	177	44,977	45,761	2,681	976	9	1	3.45E-08	180
A23.14 Ancillary Steel	3,000	20	3,020	9,800	404	146	1	1	1.47E-09	20
A32 Walls Above Grade	1,127,500	21,712	1,149,212	1,976,354	146,879	95,836	1,996	75.379615	6.95E-04	11,777
A32.1 Aluminum Framed Glazed Curtain Wall	672,700	18,434	691,134	945,859	98,549	70,319	1,836	27	3.81E-04	9,274
A32.2 Aluminum Composite Panel Projection	300,500	2,176	302,676	681,304	28,080	18,025	121	29	5.89E-05	1,537
A32.3 Perforated Metal Panel Projection	116,100	1,102	117,202	349,192	20,249	7,492	40	20	2.55E-04	965
A32.4 Board Form Concrete Finish	38,200	0	38,200	0	0	0	0	0	0.00E+00	0
B11 Partitions	273,500	4,657	278,157	561,280	45,021	20,083	355.71657	18.523641	1.84E-04	5,789
B11.1 99mm CLT Walls	57,700	324	58,024	83,782	4,909	1,788	17	1	6.30E-08	330
B11.2 239mm CLT Walls	88,500	792	89,292	204,945	12,007	4,374	41	3	1.54E-07	808
B11.3 Concrete Walls	65,100	1,119	66,219	126,073	15,432	5,400	62	6	7.77E-05	2,038
B11.4 Non Load Bearing Walls	49,600	1,972	51,572	124,262	10,338	6,674	191	7	9.56E-05	2,384
B11.5 Metal Framed Glazed Screens	12,600	449	13,049	22,219	2,335	1,847	45	1	1.06E-05	230

Table 3: Steel Design Economic-Environmental Results

Element	Direct Cost (CAD $)	Externality Cost (CAD $)	Total Cost ($)	Fossil Fuel Use (MJ)	Global Warming Potential (kg CO_2 eq)	Acidification Potential (moles H+ eq)	HH Criteria (kg PM10 eq)	Eutrophication Potential (kg N eq)	Ozone Depletion Potential (kg CFC-11 eq)	Smog Potential (kg O_3 eq)
All Elements	2,812,800	74,307	2,887,107	8,329,477	666,096	271,205	6,173	411.63434	2.55E-03	61,944
A11 Foundations	416,100	7,101	423,201	677,106	93,934	32,443	397	29	5.07E-04	12,207
A11.1 Foundations	416,100	6,959	423,059	677,106	93,934	32,443	397	29	5.07E-04	12,207
A21 Lowest Floor Construction	173,100	23,525	196,625	871,190	96,625	29,722	2,628	33.665572	4.22E-04	10,755
A21.1 150mm Concrete Slab on Grade	76,400	15,672	92,072	424,346	46,032	13,845	1,853	15	1.91E-04	5,054
A21.2 100mm Concrete Slab on Grade	21,700	4,956	26,656	111,895	11,278	3,317	605	4	4.29E-05	1,198
A21.3 Housekeeping Pads	75,000	2,896	77,896	334,949	39,316	12,560	170	14	1.88E-04	4,503
A22 Upper Floor Construction	197,300	3,714	201,014	926,041	62,719	20,176	161.54988	53.070656	1.54E-04	4,824
A22.1 Structural Steel Beams	26,400	177	26,577	86,242	3,574	1,283	5	6	1.20E-08	167
A22.2 Composite Floor Deck	45,100	2,487	47,587	331,208	38,050	11,276	129	11	1.54E-04	3,667
A22.5 Structural Steel Beams	68,700	461	69,161	224,291	9,293	3,337	12	16	3.11E-08	434
A22.6 Structural Steel Columns	11,200	89	11,289	41,510	1,818	645	2	2	5.58E-09	69
A22.7 Metal Grate Floor System	45,900	500	46,400	242,792	9,985	3,635	14	17	3.42E-08	487
A23 Roof Construction	738,800	10,222	749,022	2,944,781	183,376	58,315	402.7165	165.99649	3.35E-04	11,595
A23.1 Steel Stud Infill	112,900	315	113,215	93,384	6,535	1,659	10	4	2.65E-06	205
A23.2 200mm CMU Walls - Exterior	140,100	5,320	145,420	869,953	77,761	26,877	279	52	3.32E-04	8,141
A23.4 Composite Roof Deck	45,900	1,102	47,002	374,871	26,612	5,480	23	13	5.73E-08	489
A23.5 Structural Steel Beams	121,900	818	122,718	397,831	16,484	5,918	22	28	5.52E-08	770
A23.6 Structural Steel Columns	32,600	227	32,827	109,410	4,594	1,646	6	7	1.51E-08	205
A23.7 Open Web Steel Joists	23,200	170	23,370	82,995	3,621	1,208	4	4	1.02E-08	99
A23.8 Ancillary Steel and Lintels	22,800	258	23,058	110,963	5,338	1,877	7	3	1.36E-08	134
A23.9 Composite Roof Deck	16,900	407	17,307	138,351	9,822	2,022	8	5	2.12E-08	180
A23.10 Structural Steel Beams	70,300	471	70,771	229,332	9,504	3,411	13	16	3.18E-08	444
A23.11 Structural Steel Columns	95,700	642	96,342	312,544	12,949	4,650	17	22	4.34E-08	605
A23.12 Open Web Steel Joists	13,700	100	13,800	49,075	2,141	714	2	3	6.08E-09	59
A23.13 Ancillary Steel and Lintels	42,800	392	43,192	176,071	8,015	2,852	11	8	2.27E-08	264
A32 Walls Above Grade	1,089,300	21,712	1,111,012	1,976,354	146,879	95,836	1,996	75.379615	6.95E-04	11,777
A32.1 Aluminum Framed Glazed Curtain Wall	672,700	18,434	691,134	945,859	98,549	70,319	1,836	27	3.81E-04	9,274
A32.2 Aluminum Composite Panel Projection	300,500	2,176	302,676	681,304	28,080	18,025	121	29	5.89E-05	1,537
A32.3 Perforated Metal Panel Projection	116,100	1,102	117,202	349,192	20,249	7,492	40	20	2.55E-04	965
B11 Partitions	198,200	8,033	206,233	934,003	82,562	34,714	587.93992	54.522002	4.39E-04	10,786
B11.1 200mm CMU Walls	103,400	4,317	107,717	706,042	63,110	21,813	227	42	2.70E-04	6,607
B11.2 Non Load Bearing Walls	82,200	3,266	85,466	205,743	17,117	11,054	317	12	1.58E-04	3,949
B11.3 Metal Framed Glazed Screens	12,600	449	13,049	22,219	2,335	1,847	45	1	1.06E-05	230

Figure 2: Hybrid Design Elemental Contributions to Total Results

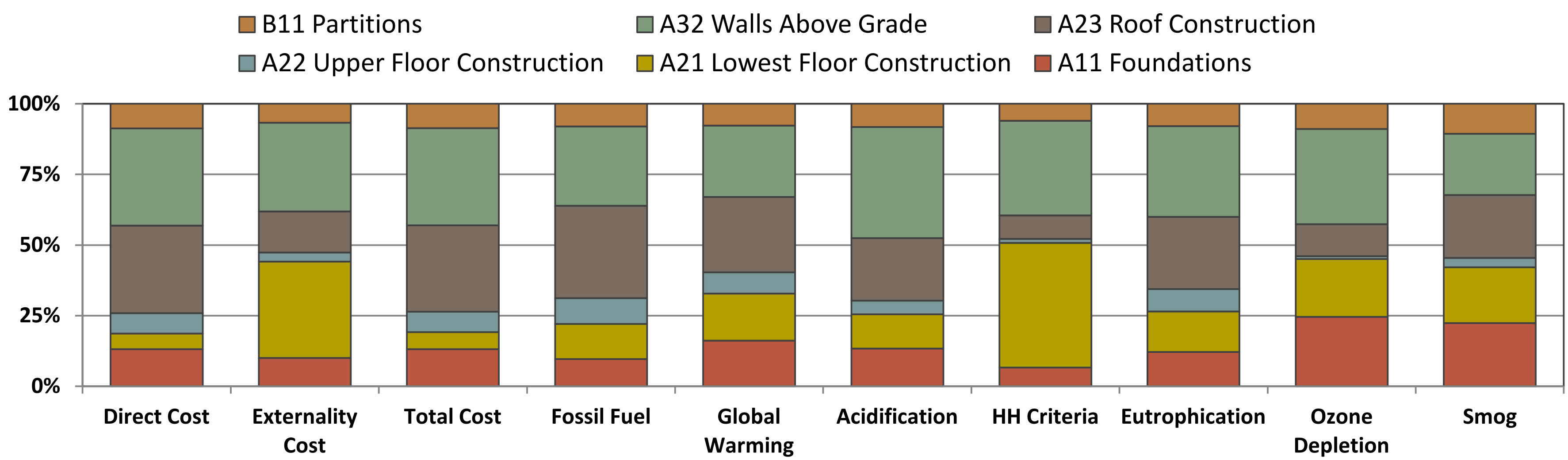


Figure 3: Steel Design Elemental Contributions to Total Results

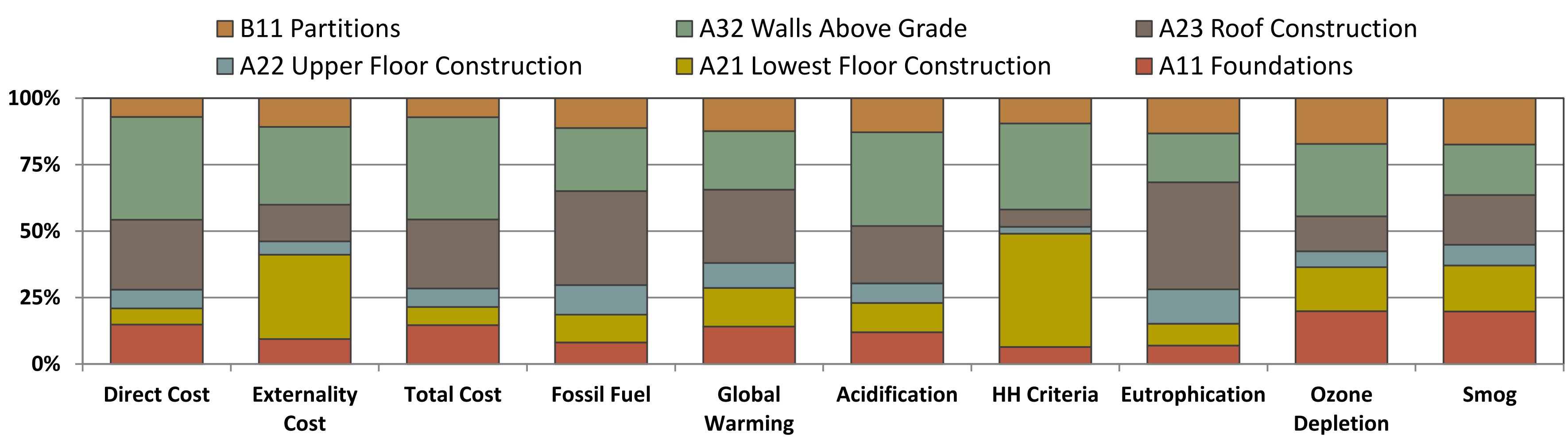


Figure 4: Normalized Economic-Environmental Comparison, all elements

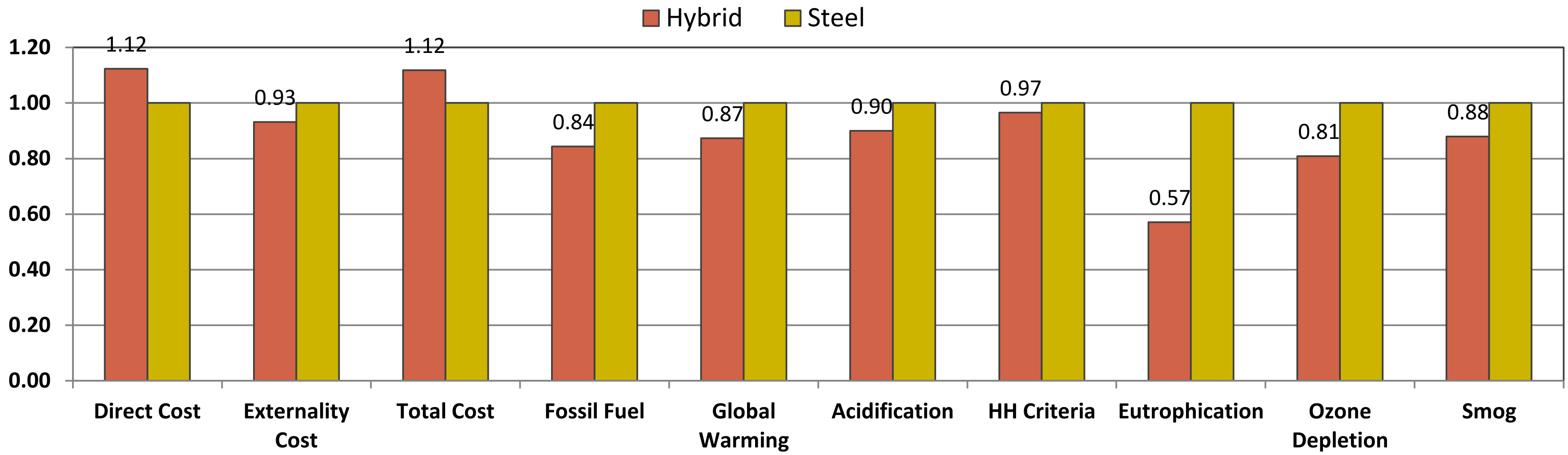


Figure 5: Normalized Economic-Environmental Comparison, elements A22, A23, B11

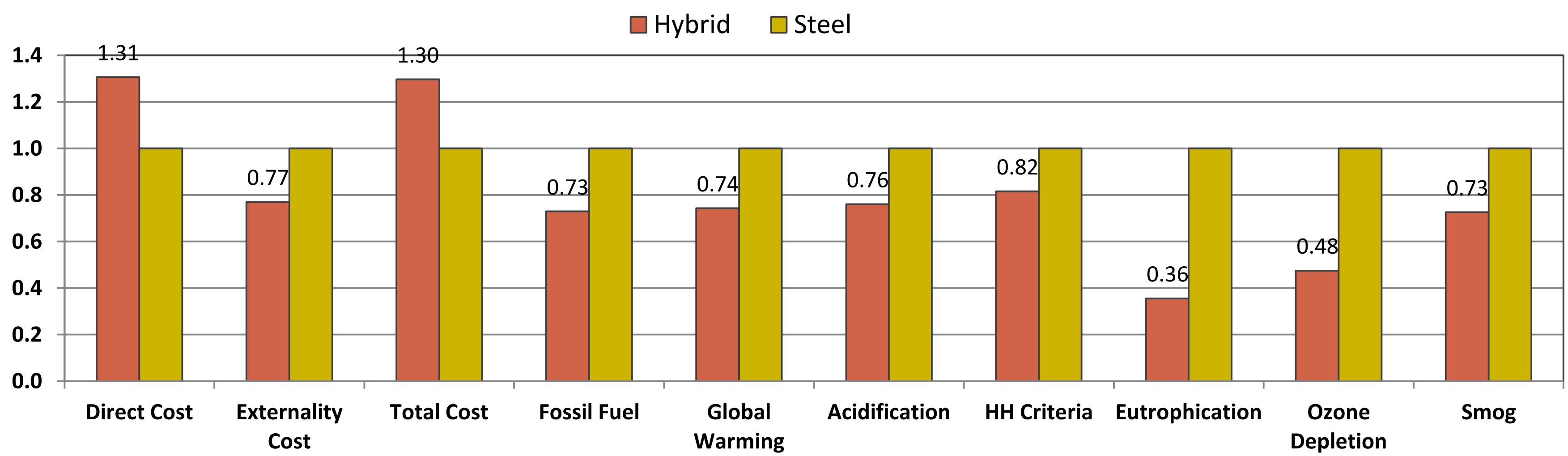


Figure 6: Global Warming Potential Comparison, by element

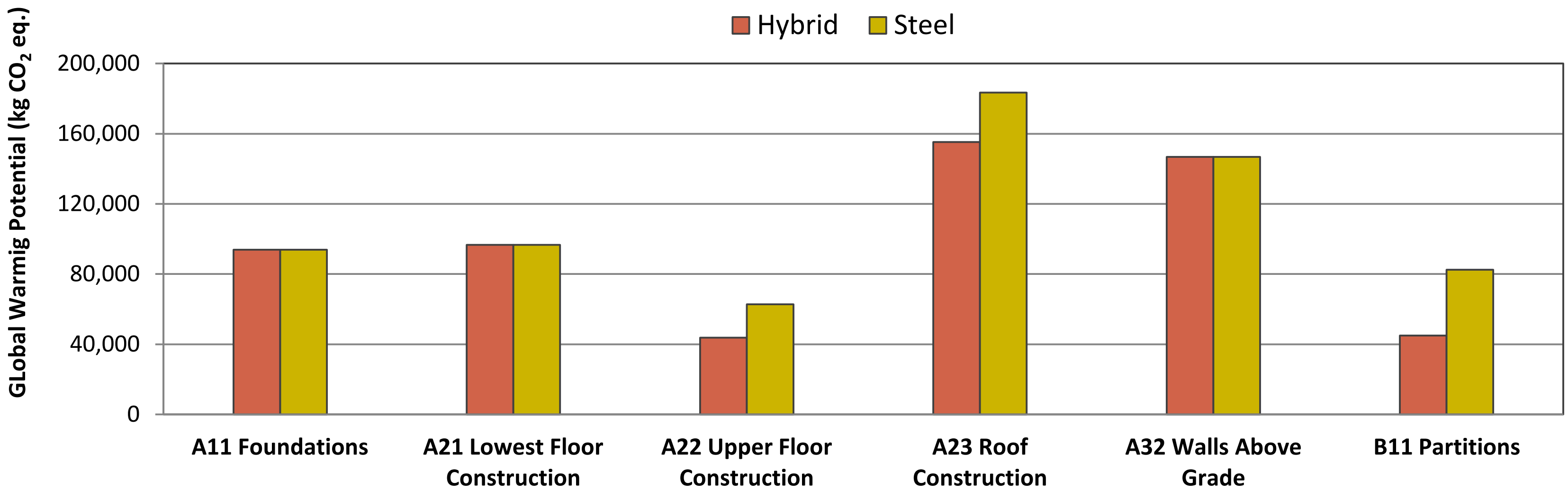


Figure 7: Comparison of Direct Cost and Global Warming Potential, by element

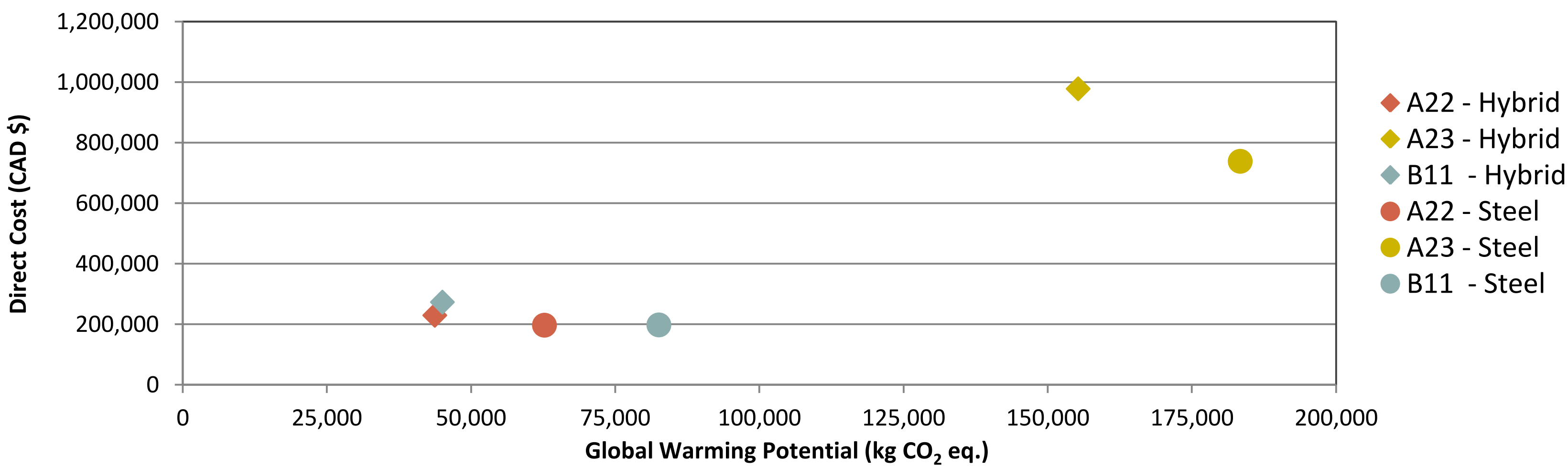


Figure 8: Fly Ash Sensitivity Analysis, all elements

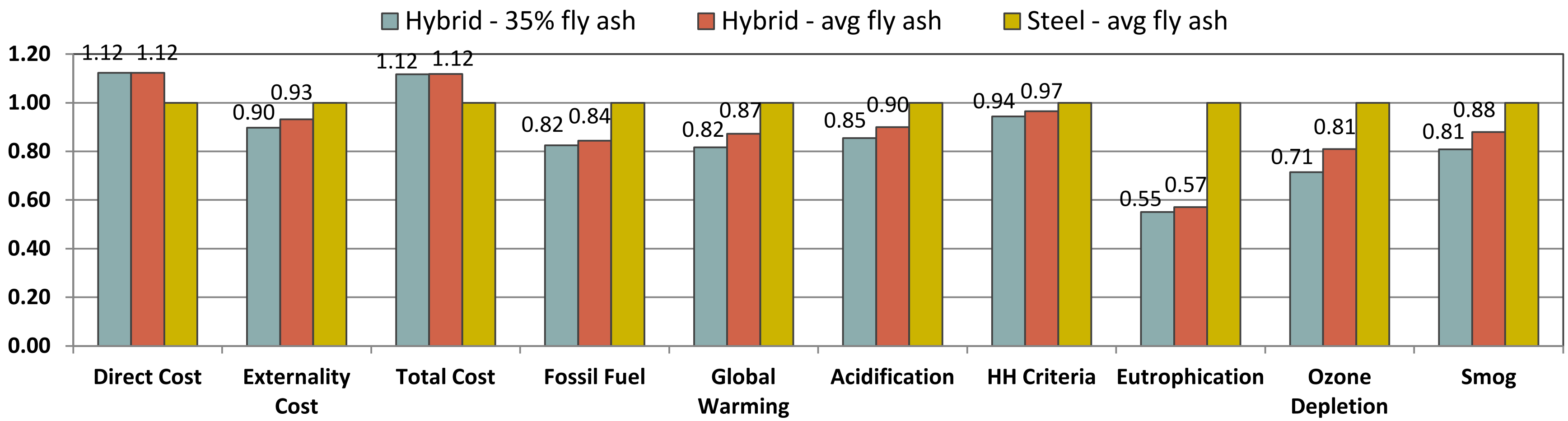
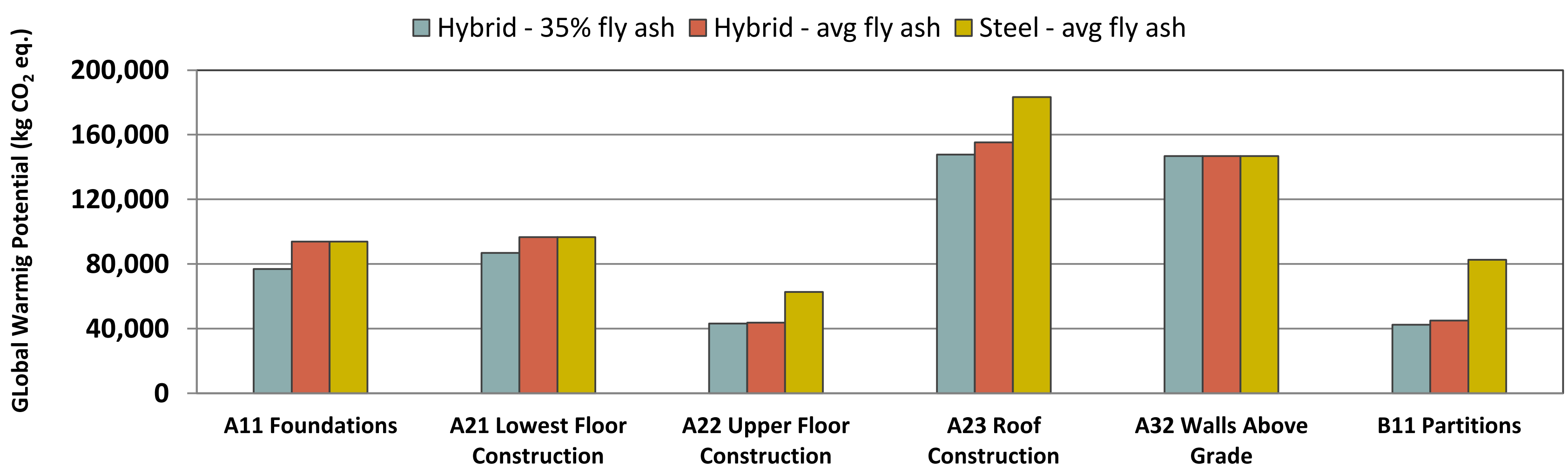


Figure 9: Global Warming Potential Fly Ash Sensitivity Analysis, by element



Appendix A: Description of Impact Indicators

(provided by the Athena Sustainable Materials Institute)

Fossil Fuel Use - MJ

Fossil fuel use is the sum of all energy sources that are drawn directly from the earth from non-renewable fossil sources such as natural gas, crude oil and coal. This indicator includes energy combusted and used as feedstock. *Feedstock energy* is that part of the primary energy entering the system which is not consumed and/or is available as fuel energy and for use outside the system boundary. Fossil fuel use is expressed in MJ.

Global Warming Potential - kg CO_2 equivalents

Global warming potentials are a midpoint metric proposed by the International Panel on Climate Change (IPCC), for the calculation of the potency of greenhouse gases relative to CO_2. The 100-year time horizons recommended by the IPCC and used by the United States for policy making and reporting are adopted within TRACI. Global warming potential (GWP) can be considered one of the most accepted LCIA categories due to the methodology and science behind the GWP calculation. GW_{P100} will be expressed on equivalency basis relative to CO_2 – that is, equivalent CO_2 mass basis i.e. tonnes of CO_2.

Acidification Potential - moles H+ equivalents

Acidification comprises processes that increase the acidity (hydrogen ion concentration, [H+]) of water and soil systems. Acidification is a more regional rather than global impact, affecting fresh water and forests as well as human health when high concentrations of SO_2 are attained. The acidification potential of an air emission is calculated on the basis of the number of H+ ions that can be produced, and is therefore expressed as potential H+ equivalents on a mass basis.

Eutrophication Potential - kg N equivalents

Eutrophication is defined as the fertilization of surface waters by nutrients that were previously scarce. This measure encompasses the release of mineral salts and their nutrient enrichment effects on waters – typically made up of phosphorous and nitrogen compounds and organic matter flowing into waterways. The result is expressed on an equivalent mass of nitrogen (N) basis. The characterization factors estimate the eutrophication potential of a release of chemicals containing N or P to air or water, per kilogram of chemical released, relative to 1 kg N discharged directly to surface freshwater.

Human Health (HH) Criteria Pollutants - kg PM_{10} equivalents

The midpoint level is based on exposure to elevated particulate matter less than 10 micrometers in diameter (PM_{10}). Particulate matter is the term for particles found in the air, including dust, dirt, soot, smoke, and liquid droplets. Emissions of SO_2 and NO_x lead to formation of the secondary particulates sulphate and nitrate. Many manmade and natural sources emit PM directly or emit other pollutants that react in the atmosphere to form PM. These solid and liquid particles come in a wide range of sizes. Particles less than 10 micrometers in diameter pose a health concern because they can be inhaled into and accumulate in the respiratory system. Particles less than 2.5 micrometers in diameter (PM2.5) are referred to as "fine" particles and are believed to pose the greatest health risks. Because of their small size, fine particles can lodge deep in the lungs.

Ozone Depletion - kg CFC-11 equivalents

Stratospheric ozone depletion is the reduction of the protective ozone within the stratosphere caused by emissions of ozone-depleting substances. International consensus exists on the use of ozone depletion potentials, a metric proposed by the World Meteorological Organization for calculating the relative importance of CFCs, hydrochlorofluorocarbons (HFCs), and halons expected to contribute significantly to the breakdown of the ozone layer. TRACI is using the ozone depletion potentials published in the Handbook for the International Treaties for the Protection of the Ozone Layer (UNEP-SETAC 2000), where chemicals are characterized relative to CFC-11.

Smog Potential - kg O_3 equivalents

Under certain climatic conditions, air emissions from industry and transportation can be trapped at ground level where, in the presence of sunlight, they produce photochemical smog, a symptom of photochemical ozone creation potential (POCP). While ozone is not emitted directly, it is a product of interactions of volatile organic compounds (VOCs) and nitrogen oxides (NO_x). The “smog” indicator is expressed on a mass of equivalent ozone (O_3) basis.

Appendix B: Hybrid Design Cost Information (from Hanscomb)

Element	Description	Quantity	Unit	Unit Rate	Total	Included?
TOTAL	BUILDING				$3,264,500	
A	SHELL				$2,965,000	
A1	Substructure				$416,100	
A11	Foundations				$416,100	
1	Allowances for foundations under normal soil conditions (includes strip, footings, foundation walls, excavation and backfill)	1,387	m2	$300.00	$416,100	Y
A2	Structure				$1,421,400	
A21	Lowest Floor Construction				$173,100	
1	Concrete slab on grade (150mm)	1,039	m2	$73.50	$76,400	Y
	- Concrete - supply and place	156	m3	$230.00		
	- Reinforcing	4,083	kg	$1.90		
	- Granular material (allow 200mm)	208	m3	$75.00		
	- Finishing	1,039	m2	$11.50		
	- Construction joints	1,039	m2	$5.00		
2	Concrete slab on grade (100mm)	348	m2	$62.40	$21,700	Y
	- Concrete - supply and place	35	m3	$230.00		
	- Reinforcing	1,368	kg	$1.90		
	- Granular material (allow 200mm)	70	m3	$75.00		
	- Finishing	348	m2	$11.50		
	- Construction joints	348	m2	$5.00		
3	Allowance for housekeeping pads	1	Sum	$75,000.00	$75,000	Y
A22	Upper Floor Construction				$269,900	
1	Cross laminated timber floor (239mm, common 7-ply)	276	m2	$293.10	$80,900	Y
	- Concrete topping (allow 50mm)	14	m3	$230.00		
	- Finishing	276	m2	$11.50		
	- Cross laminated timber decking	276	m2	$270.00		
2	Composite floor slab	24	m2	$120.80	$2,900	Y
	- Concrete topping (140mm)	3	m3	$230.00		
	- Finishing	24	m2	$11.50		
	- Composite floor deck (Comfloor 210)	24	m2	$80.00		
3	Glulam beams	1	Sum	$3,100.00	$3,100	Y
	- 265x380 D. Fir	1	m3	$2,800.00		
	- 265x141 D. Fir	1	Sum	$300.00		
4	Structural steel columns	1	Sum	$2,000.00	$2,000	Y
	- HSS 127x127x9.5	300	kg	$6.00		
	- Allowance for connections	1	Sum	$200.00		
5	Stair c/w/ hand and guard rail	1	Sum	$10,000.00	$10,000	N
	- Stair #1	1	No.	$10,000.00		
6	Feature stair @ entrance	1	Sum	$25,000.00	$25,000	N
	- Cast in place concrete stair c/w sand blasted finish, wood handrail and structural glass	1	Sum	$25,000.00		

Element	Description	Quantity	Unit	Unit Rate	Total	Included?
	Mezzanine Construction					
7	Structural steel beams	1	Sum	$68,400.00	$68,400	Y
	- C230x22	3,190	kg	$6.00		
	- W610x82	5,248	kg	$6.00		
	- W610x92	1,932	kg	$6.00		
	- Allowance for connections	1,037	kg	$6.00		
8	Structural steel columns	1	Sum	$9,500.00	$9,500	Y
	- HSS 152x152x6.4	255	kg	$6.00		
	- HSS 203x203x6.4	692	kg	$6.00		
	- HSS 305x305x13	400	kg	$6.00		
	- Allowance for connections	226	kg	$6.00		
9	Metal grate floor system	287	m2	$220.00	$63,100	Y
10	Steel stairs to mezzanine	1	Sum	$5,000.00	$5,000	N
	- Stairs to mezzanine from Level 2 (channel strunger and steel grating stairs)	1	Sum	$5,000.00		
A23	Roof Construction				$978,400	
1	Concrete walls - exterior	553	m2	$350.00	$193,600	Y
2	Cross lamianted timber walls - exterior (239mm, common 7-ply)	454	m2	$295.00	$133,900	Y
	Roof Construction - Lower Roof					
3	Cross laminated timber roof deck	888	m2	$270.00	$239,800	Y
	- 239mm, common 7-ply cross laminated timber decking	888	m2	$270.00		
4	Composite roof deck	217	m2	$123.50	$26,800	Y
	- Concrete topping (140mm)	30	m3	$230.00		
	- Finishing	217	m2	$11.50		
	- Composite roof deck (Comfloor 210)	217	m2	$80.00		
5	Structural steel beams	1	Sum	$10,700.00	$10,700	Y
	- HSS 305x203x9.5	1,211	kg	$6.00		
	- Allowance for connections	530	kg	$6.50		
6	Glulam beams	1	Sum	$74,100.00	$74,100	Y
	- 130x380 D. Fir	1	Sum	$1,300.00		
	- 215x494 D. Fir	1	Sum	$2,800.00		
	- 215 570 D. Fir	3	m3	$2,800.00		
	- 265x684 D. Fir	12	m3	$2,800.00		
	- 315x646 D. Fir	5	m3	$2,800.00		
	- 365x1064 D. Fir	5	m3	$2,800.00		
7	Cross laminated timber beam	1	Sum	$6,200.00	$6,200	Y
	- 239mm, common 7-ply header	21	m2	$295.00		
8	Structural steel columns	1	Sum	$5,100.00	$5,100	Y
	- HSS 127x127x9.5	799	kg	$6.00		
	- Allowance for connections	40	kg	$6.50		

Element	Description	Quantity	Unit	Unit Rate	Total	Included ?
	<u>Roof Construction - Upper Roof</u>					
9	Cross laminated timber roof deck	376	m2	$269.90	$101,500	Y
	- 239mm, common 7-ply cross laminated timber decking	376	m2	$270.00		
10	Structural steel beams	1	Sum	$30,200.00	$30,200	Y
	- W200x36	792	kg	$6.00		
	- W200x86	602	kg	$6.00		
	- W250x18	342	kg	$6.00		
	- W360x52	728	kg	$6.00		
	- HSS 152x152x6.4	933	kg	$6.00		
	- HSS 305x203x9.5	998	kg	$6.00		
	- Allowance for connections	573	kg	$6.50		
11	Glulam beams	1	Sum	$56,000.00	$56,000	Y
	- 130x342 D. Fir	1	Sum	$2,750.00		
	- 265x494 D. Fir	7	m3	$2,800.00		
	- 265x684 D. Fir	7	m3	$2,800.00		
	- 315x646 D. Fir	5	m3	$2,800.00		
12	Structural steel columns	1	Sum	$52,700.00	$52,700	Y
	- HSS 102x102x8.0	332	kg	$6.00		
	- HSS 203x203x9.5	4,881	kg	$6.00		
	- HSS 254x254x9.5	1,212	kg	$6.00		
	- HSS 305x305x13	1,921	kg	$6.00		
	- Allowance for connections	401	kg	$6.50		
13	Glulam Columns	1	Sum	$44,800.00	$44,800	Y
	- 265x684 D. Fir	16	m3	$2,800.00		
14	Ancillary steel	1	Sum	$3,000.00	$3,000	Y
	- Vertical bracing	1	Sum	$3,000.00		
A3	Exterior Enclosure				$1,127,500	
A32	Walls Above Grade				$1,127,500	
1	Aluminum framed glazed curtain wall	872	m2	$771.40	$672,700	Y
	- Double glazed curtain wall	451	m2	$290.00		
	- Fitted glass	166	m2	$370.00		
	- Metal louvres	191	m2	$250.00		
	- Metal screen	64	m2	$235.00		
	- Aluminum frame	872	m2	$475.00		
	- Extra over for ceramic frit lettering	1	Sum	$3,500.00		
2	Aluminum composite panel projection c/w steel supports (Area provided by client)	634	m2	$474.00	$300,500	Y
	- Aluminum composite panels	634	m2	$300.00		
	- Allowance for structural steel supports	19,020	kg	$5.80		

Element	Description	Quantity	Unit	Unit Rate	Total	Included?
3	Perforated metal panel projection c/w steel supports (Area provided by client)	328	m2	$354.00	$116,100	Y
	- Perforated metal panels	328	m2	$180.00		
	- Allowance for structural steel supports	9,840	kg	$5.80		
4	Extra over for board from concrete finish (wall carried in structure)	318	m2	$120.00	$38,200	Y
5	Cross laminated timber walls (carried in A23 Roof Construction)	1	Nil	$0.00	$0	N/A
6	Concrete Walls (carried in A23 Roof Construction)	1	Nil	$0.00	$0	N/A
B	INTERIORS				$299,500	
B1	Partitions & Doors				$299,500	
B11	Partitions				$299,500	
1	Cross laminated timber walls (99mm, common 3-ply)	296	m2	$195.00	$57,700	Y
2	Cross laminated timber walls (239mm, common 7-ply)	300	m2	$295.00	$88,500	Y
3	Concrete walls	217	m2	$300.00	$65,100	Y
4	Gypsum board on both sides of metal studs c/w sounds attenuation batts	451	m2	$110.00	$49,600	Y
5	Metal framed glazed screens	28	m2	$450.00	$12,600	Y
6	Structural glass guard to balcony	27	m	$900.00	$24,300	N
7	Extra over for moisture resistance gypsum board	227	m2	$6.00	$1,400	N
8	Extra over for fire rated partition	56	m2	$6.00	$300	N

Appendix C: Steel Design Cost Information (from Hanscomb)

Element	Description	Quantity	Unit	CAD ($)		Included?
				Unit Rate	Total	
TOTAL	BUILDING				2,878,800	
A	SHELL				2,654,600	
A1	Substructure				416,100	
A11	Foundations				416,100	
1	Allowances for foundations under normal soil conditions (includes strip, footings, foundation walls, excavation and backfill)	1,387	m2	$300.00	416,100	Y
A2	Structure				1,149,200	
A21	Lowest Floor Construction				173,100	
1	Concrete slab on grade (150mm)	1,039	m2	$73.50	76,400	Y
	- Concrete - supply and place	156	m3	$230.00		
	- Reinforcing	4,083	kg	$1.90		
	- Granular material (allow 200mm)	208	m3	$75.00		
	- Finishing	1,039	m2	$11.50		
	- Construction joints	1,039	m2	$5.00		
2	Concrete slab on grade (100mm)	348	m2	$62.40	21,700	Y
	- Concrete - supply and place	35	m3	$230.00		
	- Reinforcing	1,368	kg	$1.90		
	- Granular material (allow 200mm)	70	m3	$75.00		
	- Finishing	348	m2	$11.50		
	- Construction joints	348	m2	$5.00		
3	Allowance for housekeeping pads	1	Sum	$75,000.00	75,000	Y
A22	Upper Floor Construction				237,300	
1	Structural steel beams	1	Sum	$26,400.00	26,400	Y
	- W150x30	420	kg	$6.00		
	- W250x18	450	kg	$6.00		
	- W310x21	945	kg	$6.00		
	- W310x39	351	kg	$6.00		
	- W360x91	1,820	kg	$6.00		
	- Allowance for connections	399	kg	$6.25		
2	Composite floor deck	300	m2	$154.70	45,100	Y
	- Concrete - supply and place	86	m3	$220.00		
	- Finishing	300	m2	$11.50		
	- Composite decking system	300	m2	$80.00		
3	Stair c/w/ hand and guardrail	1	Sum	$10,000.00	10,000	N
	- Stair #1	1	No.	$10,000.00		
4	Feature stair @ entrance	1	Sum	$25,000.00	25,000	N
	- Cast in place concrete stair c/w sand blasted finish, wood handrail and structural glass	1	Sum	$25,000.00		
	<u>Mezzanine Construction</u>					
5	Structural steel beams	1	Sum	$68,700.00	68,700	Y
	- C230x22	3,190	kg	$6.00		
	- W610x82	5,248	kg	$6.00		
	- W610x92	1,932	kg	$6.00		
	- Allowance for connections	1,037	kg	$6.25		
6	Structural steel columns	1	Sum	$11,200.00	11,200	Y
	- W360x134	603	kg	$6.00		
	- W360x91	614	kg	$6.00		
	- HSS 152x152x6.4	255	kg	$6.00		
	- HSS 203x203x6.4	173	kg	$6.00		
	- Allowance for connections	226	kg	$6.25		

Element	Description	Quantity	Unit	CAD ($)		Included?
				Unit Rate	Total	
7	Metal grate floor system	287	m2	$160.00	45,900	Y
8	Steel stairs to mezzanine	1	Sum	$5,000.00	5,000	N
	- Stairs to mezzanine from Level 2 (channel strunger and steel grating stairs)	1	Sum	$5,000.00		
A23	Roof Construction				738,800	
1	Steel studs infill with exterior sheathing and interior GWB	370	m2	$305.00	112,900	Y
2	200mm CMU walls - exterior	637	m2	$220.00	140,100	Y
3	Concrete walls - interior (included in B11, Partitions)	1	Nil	$0.00	0	N/A
	<u>Roof Construction - Lower Roof</u>					
4	Composite roof deck	1,019	m2	$45.00	45,900	Y
	- Metal deck (38mm)	1,019	m2	$45.00		
5	Structural steel beams	1	Sum	$121,900.00	121,900	Y
	- W250x18	2,412	kg	$6.00		
	- W250x28	2,632	kg	$6.00		
	- W310x24	1,152	kg	$6.00		
	- W310x33	1,848	kg	$6.00		
	- W310x39	234	kg	$6.00		
	- W410x54	432	kg	$6.00		
	- W530x85	6,205	kg	$6.00		
	- W610x125	1,500	kg	$6.00		
	- W610x140	1,960	kg	$6.00		
	- Allowance for connections	1,858	kg	$6.25		
6	Structural steel columns	1	Sum	$32,600.00	32,600	Y
	- HSS127x127x6.4	278	kg	$6.00		
	- W360x91	4,641	kg	$6.00		
	- Allowance for connections	492	kg	$6.25		
7	Open web steel joists	1	Sum	$23,200.00	23,200	Y
	- 650 OWSJ@15.4kg/m	3,650	kg	$5.75		
	- Allowance for connections	366	kg	$6.00		
8	Ancillary steel and lintels	1	Sum	$22,800.00	22,800	Y
	- HSS305x305x9.5	3,374	kg	$6.00		
	- Allowance for connections	413	kg	$6.25		
	<u>Roof Construction - Upper Roof</u>					
9	Composite roof deck	376	m2	$44.90	16,900	Y
	- Metal deck (38mm)	376	m2	$45.00		
10	Structural steel beams	1	Sum	$70,300.00	70,300	Y
	- W410x39	1,131	kg	$6.00		
	- W410x74	6,290	kg	$6.00		
	- W530x85	3,145	kg	$6.00		
	- Allowance for connections	1,095	kg	$6.25		
11	Structural steel columns	1	Sum	$95,700.00	95,700	Y
	- W360x134	4,556	kg	$6.00		
	- W460x97	9,894	kg	$6.00		
	- Allowance for connections	1,446	kg	$6.25		
12	Open web steel joists	1	Sum	$13,700.00	13,700	Y
	- 500 OWSJ@13kg/m	2,158	kg	$5.75		
	- Allowance for connections	216	kg	$6.00		
13	Ancillary steel and lintels	1	Sum	$42,800.00	42,800	Y
	- HSS305x305x9.5	3,374	kg	$6.00		
	- Allowance for vertical bracing	1	Sum	$10,000.00		
	- Allowance for framing to stacks	1	Sum	$10,000.00		
	- Allowance for connections	413	kg	$6.25		

Element	Description	Quantity	Unit	CAD ($)		Included?
				Unit Rate	Total	
A3	Exterior Enclosure				1,089,300	
A32	Walls Above Grade				1,089,300	
1	Aluminum framed glazed curtain wall	872	m2	$771.40	672,700	Y
	- Double glazed curtain wall	451	m2	$290.00		
	- Fitted glass	166	m2	$370.00		
	- Metal louvres	191	m2	$250.00		
	- Metal screen	64	m2	$235.00		
	- Aluminum frame	872	m2	$475.00		
	- Extra over for ceramic frit lettering	1	Sum	$3,500.00		
2	Aluminum composite panel projection c/w steel supports (Area provided by client)	634	m2	$474.00	300,500	Y
	- Aluminum composite panels	634	m2	$300.00		
	- Structural steel supports	19,020	kg	$5.80		
3	Perforated metal panel projection c/w steel supports (Area provided by client)	328	m2	$354.00	116,100	Y
	- Perforated metal panels	328	m2	$180.00		
	- Structural steel supports	9,840	kg	$5.80		
4	Extra over for board from concrete finish (not applicable for CMU walls)	1	Nil	$0.00	0	N/A
B	INTERIORS				224,200	
B1	Partitions & Doors				224,200	
B11	Partitions				224,200	
1	200mm CMU wall	517	m2	$200.00	103,400	Y
2	Gypsum board on both sides of metal studs c/w sounds attenuation batts	747	m2	$110.00	82,200	Y
3	Metal framed glazed screens	28	m2	$450.00	12,600	Y
4	Structural glass guard to balcony	27	m2	$900.00	24,300	N
5	Extra over for moisture resistant gypsum board	227	m2	$6.00	1,400	N
6	Extra over for fire resistant gypsum board	56	m2	$6.00	300	N